N95-10641

303541

TOMS TOTAL OZONE DATA COMPARED WITH NORTHERN LATITUDE DOBSON GROUND STATIONS

B. Heese

Alfred-Wegener-Institut, Bremerhaven, Germany

K. Barthel, Ø. Hov

University in Bergen /Nansen Environmental and Remote Sensing Center, Bergen, Norway

ABSTRACT

Ozone measurements from the Total Ozone Mapping Spectrometer on the Nimbus 7 satellite are compared with ground-based measurements from five Dobson stations at northern latitudes to evaluate the accuracy of the TOMS data, particularly in regions north of 50°N. The measurements from the individual stations show mean differences from −2.5% up to +8.3% relative to TOMS measurements and two of the ground stations, Oslo and Longyearbyen, show a significant drift of +1.2% and +3.7% per year, respectively. It can be shown from nearly simultaneous measurements in two different wavelength double pairs at Oslo that at least 2% of the differences result from the use of the CC' wavelength double pair instead of the standard AD wavelength double pair. Since all Norwegian stations used the CC' wavelength double pair exclusively a similar error can be assumed for Tromsø and Longyearbyen. A comparison between the tropospheric ozone content in TOMS data and from ECC ozonesonde measurements at Ny-Ålesund and Bear Island shows that the amount of tropospheric ozone in the standard profiles used in the TOMS algorithm is too low, which leads to an error of about 2% in total ozone. Particularly at high solar zenith angles (>80°), Dobson measurements become unreliable. They are up to 20% lower than TOMS measurements averaged over solar zenith angles of 88° to 89°.

INTRODUCTION

At high latitudes, errors in TOMS total ozone are possibly larger than is generally assumed. The solar zenith angles are higher, and there are generally more variations in total ozone than at middle and low latitudes. When using TOMS data for studies of the ozone climatology and for correlations with synoptic meteorological parameters at northern latitudes it is important to know their accuracy. The objective of this study is to identify and possibly quantify errors in TOMS data by comparison with Dobson measurements at five stations at northern latitudes.

DATA AND METHOD

TOMS data exist in several versions, version 6 being the most recent. Relative to version 5, the version 6 data have been corrected for a drift caused by the degradation of the instrument's diffuser plate using the internal "pair-justification" technique. These data are in agreement within the error limits with the average of 39 ground-based Dobson stations [Herman et al., 1991]. The TOMS data were prepared by the Ozone Processing Team of NASA Goddard Space Flight Center: J.R. Herman, R. Hudson, R.D. McPeters and R. Stolarski, Z. Ahmad, X.Y. Gu, S. Taylor, and C. Wellemeyer.

Ten years of GRID-TOMS version 5 data (1979 - 1988) and 4 years of version 6 data (1986 - 1989) have been compared with five Dobson stations at high latitudes: Oslo (59.5°N,10.5°E), Tromsø (69.4°N,18.6°E), Longyearbyen (78.1°N,15.4°E), Reykjavik (64.1°N,21.5°W), and Resolute (74.4°N, 94.6°W). The measurements at Tromsø and Longyearbyen began again in winter 1984 after a break in 1969, so that there are only 4 years for comparison. The 1979-1985 TOMS version 6 data became available in spring 1991 when most of the work for this study was done. Since the objective of this study is to find reasons for the differences between TOMS and Dobson ozone estimates and since the drift in the version 5 data for the respective years is small (0.25% per year from November 1978 to June.1982 and 0.51% per year from July 1982 to December 1985) [Fleig et al., 1988a], the version 5 data for the years 1979 to 1985 are sufficient for this purpose and can be used together with the version 6 data.

Errors of ± 2% for the TOMS data [Fleig, 1988b] and ± 3% for a typical good Dobson measurement [Basher, 1982] are assumed, so that the accuracy of this comparison is ±3.6% (rms).

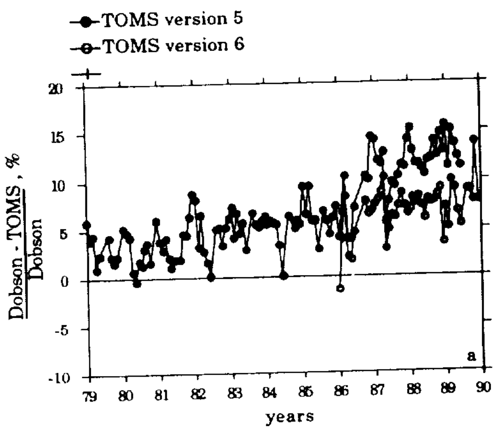
RESULTS

Figures 1a and 1b show the monthly mean relative differences (Dobson - TOMS) / Dobson for Oslo and Reykjavik calculated for ground and satellite measurements taken on the same day during at least 13 days in the given month. The limit of 13 days per month is chosen to obtain a sufficient number of monthly mean values, particulary for the months around the polar night.

Almost all Dobson measurements at the five stations show greater annual mean ozone values than the TOMS total ozone of the version 5 data. Only the first 7 years at the Reykjavik station have differences less than or equal to zero (Table 1). If direct-overpass TOMS data, which have a higher resolution of about 50 km^2, are used instead of gridded TOMS data, their relative differences to Dobson measurements do not change significantly.

The relative differences at the stations with long measurement series show a significant annual drift of +1.0% at Oslo, +0.7% at Resolute, and +0.5% at Reykjavik, which is based upon the slope of a linear regression through the data. These individual drifts are comparable with the two-part linear fit to the drift found by Fleig et al. [1988a].

Table 2 shows the annual mean percentage differences between the ground measurements and the TOMS data of the version 6. Since the drift should be corrected in these TOMS data, no drift should occur relative to stable ground stations. An observed drift in the relative differences at the ground stations in Oslo and Longyearbyen of +1.2% and +3.7% per year, respectively, or rather a shift from 1986 to 1987 of 2.5% and a small drift of 0.6% the following years at Oslo and a shift from 1987 to 1988 of 2.1% and 7.7% from 1988 to 1989 at Longyearbyen indicates a drift in these Dobson instruments or a shift in the observing routine at these stations. Tromsø, Reykjavik and Resolute show no significant drift, which is indicated by a low square correlation coefficient r^2.



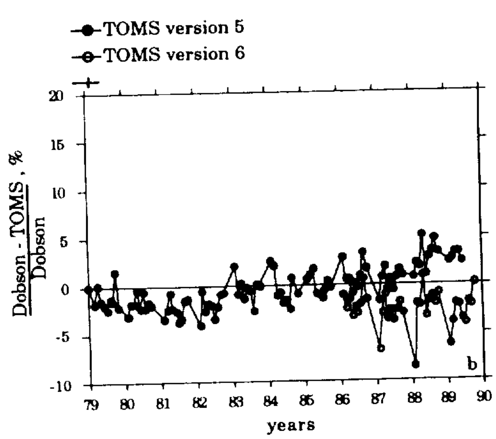


Fig. 1. Monthly mean relative differences (Dobson - TOMS) / Dobson at the ground stations in (a) Oslo and (b) Reykjavik. TOMS version 5 (solid circles) and version 6 (open circles), markers indicate new year.

For each station the relative mean difference to TOMS for the years 1986 to 1989 has been calculated from all monthly mean differences. It is as high as +6.9% and +8.3% at Oslo and Longyearbyen but lower at the other stations and within the accuracy of ±3.6% for this comparison: Tromsø has a mean difference of +2.9%, and Resolute has a mean difference of +1.2%, while Reykjavik is the only station with a negative mean difference of -2.5%.

TABLE 1.: Annual Mean Relative Differences Between Satellite and Ground-Based Measurements of Total Ozone: (Dobson-TOMS) / Dobson, (Version 5)

Year	Oslo	Tromsø	Longyb.	Reykjavik	Resolute
1979	3.1			-1.2	0.04
1980	2.9			-1.7	0.9
1981	3.8			-2.3	0.6
1982	4.3			-1.8	1.2
1983	5.6			-0.3	1.3
1984	5.0			-0.3	1.0
1985	6.5	7.4	9.8	0.02	4.6
1986	7.9	6.6	7.6	1.0	4.2
1987	10.9	5.7	8.4	0.5	3.5
1988	12.6	8.0	13.2	2.8	6.7

TABLE 2.: Annual Mean Relative Differences Between Satellite and Ground-Based Measurements of Total Ozone : (Dobson-TOMS) / Dobson, (Version6)

Year	Oslo	Tromsø	Longyb.	Reykjavik	Resolute
1986	4.5	4.0	5.3	-1.8	1.7
1987	7.0	2.4	5.7	-3.1	0.1
1988	7.5	1.8	8.8	-2.3	2.3
1989	8.2	3.2	16.5	-2.8	0.5

All stations show individual differences relative to the TOMS version 6 data. While Tromsø, Reykjavik, and Resolute are within the error range of ±3.6% for this comparison, the difference between TOMS and Dobson at Oslo and Longyearbyen is greater than 3.6% and increases from 1986 to 1989, indicating a drift in these ground-based instruments. Some reasons for these differences have been studied for both the Dobson and TOMS measurements.

Since the relative differences are larger for all Norwegian stations, a common source of error may be present in the observation technique. Dobson measurements with the AD wavelength-pair at direct sun are standard, since they are least dependent on atmospheric scattering. The C wavelength pair is to be used together with the C' wavelength pair (332 nm, 453 nm) when clouds are present . Additionally, the pathway of the radiation through the atmosphere may be longer, which is quite important for observing stations in the north according to the relatively high solar zenith angles. However, the ozone values have to be taken from empirical charts derived from comparisions with AD measurements, since the algorithm is valid only for AD measurements [Basher, 1982]. These values may be less accurate, especially if the charts are not quite actual. All Norwegian stations measured exclusively with the CC' wavelength double pair until 1990 to obtain a homogeneous time series, while the other two stations also used the AD double pair if weather conditions permited. This choice of the wavelength pair seems to produce errors.

Simultaneous measurements with the C wavelength pair (311 nm, 332 nm) and the AD double pair (305 nm, 325 nm; 317 nm, 339 nm) taken at direct sun in Oslo by S.H.H. Larsen, Physical Institute, from May until October 1990 show systematically higher monthly mean values in observed total ozone from the C wavelength pair between 9.1 and 21.1 DU. (Figure 2). These differences amount to 2% - 7% of the observed total ozone column. So the measurements with the CC' wavelength pair at the Norwegian stations cause an error of at least 2% in total ozone.

Thus one reason for the systematically higher Dobson ozone-values could be found in the permanent use of a different wavelength pair than the standard AD wavelengths. Since

1990 the Norwegian stations have also used the AD wavelength double pair if weather conditions permit (S.H.H. Larsen, personal communication, 1991) so this error should decrease in the measurements after 1989.

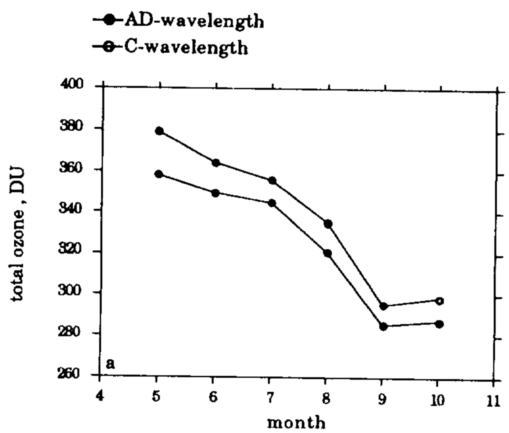


Fig. 2. Monthly mean total ozone from Dobson measurements at Oslo with the AD wavelength double pair (solid circles) and C wavelength pair (open circles) in 1990.

A second possible error source lies in the correction of TOMS measurements to tropospheric ozone, which is measured only partially because the effective reflecting surface for the backscattered radiance lies in the upper troposphere. So the amount below this layer, i.e., most of the tropospheric ozone, depends on the standard ozone profiles in the TOMS algorithm. These standards are fixed climatological, annual means. Thus seasonal and day to day variations up to 50% in tropospheric ozone and a long term trend of 0.5 - 1.0% per year observed by sonde measurements at several stations in the northern hemisphere [Bojkov, 1988] will not be measured by TOMS.

To study the resultant error, the ozone amount in the two lowest layers (up to 240 hPa) of the TOMS standard profiles were compared with the amount in the same layer measured by electrochemical concentration cell (ECC) ozonesondes at Ny-Ålesund and on Bear Island in 1989. The layers from ground up to 240 hPa represent the troposphere only roughly but allow for an approximation of the error size. ECC sonde frequency was irregular, in particular at Ny-Ålesund, and some sondes at both stations were destroyed at low altitude. They are omitted, and the remaining number of sonde measurements are 25 for Ny Ålesund and 28 for Bear Island. The sonde data have been made available by the German Alfred Wegener Institute (AWI), the Norwegian Institute for Air Research (NILU), and the Norwegian Meteorological Institute (DNMI).

Figure 3 show that the tropospheric ozone of almost all ECC measurements at Ny-Ålesund are higher than in the TOMS standard profiles, especially in summer. The same was found for Bear Island. This shows that the seasonal variations of tropospheric ozone, i.e., the higher values in summer, were not measured by TOMS.

The resultant error in total ozone can be seen from the relative differences between TOMS and ECC sonde measurements (Figure 4). Averaged over all days with observations, the mean difference is +2.3% at Ny-Ålesund and +0.8% at Bear Island. At these two stations, roughly 1 to 2% more total ozone is measured by the sondes than by TOMS. To find the part of this difference caused by the standard ozone profiles in the TOMS algorithm, the tropospheric ozone in TOMS total ozone is replaced by the value measured by the ECC sondes. Then the averaged relative difference in total ozone changes significantly at both stations by about -2% (Figure 4).

The ECC measurements are quite good in the troposphere, about ±2% error (Komhyr, 1985) Hence, the TOMS total ozone measurements are at least 2% too low and show seasonal variations because of the dependence of the tropospheric ozone amount in the standard ozone profiles in the algorithm.

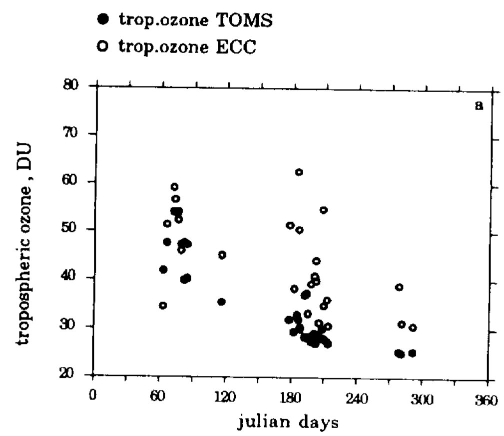


Fig. 3. Tropospheric ozone from TOMS standard profiles and ECC sonde measurements in Ny Ålesund in 1989.

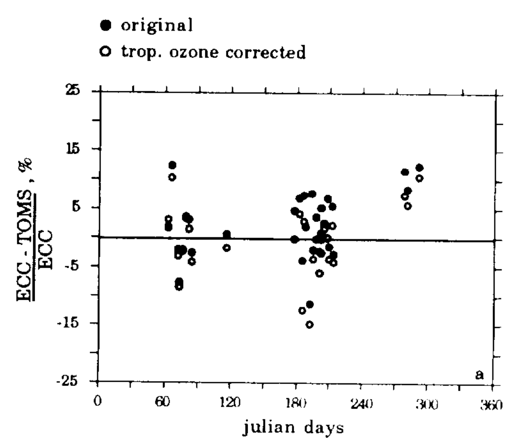


Fig. 4. Relative differences in total ozone between TOMS and ECC sonde measurements (ECC - TOMS) / ECC in Ny Ålesund. Original TOMS measurements (solid circles) and TOMS with tropospheric ozone corrected (open circles).

Another possible error source is the high solar zenith angle (SZA) at the time of observation. The relative differences between TOMS version 6 and Dobson measurements for the years 1986 to 1989 versus the TOMS SZA (Figure 5) show lower values as well as larger scatter at SZA greater than 80°. The larger scatter is probably caused by the higher dependence of TOMS total ozone on the standard vertical profile, since the reflecting surface moves upward into the ozone layer at high SZA [Dave and Mateer, 1967; Pommereau, 1989] and the path length of UV radiance through the atmosphere becomes greater.

At the Reykjavik station, three February mean relative differences in the 4 years of the version 6 data were as low as -6.7%, -8.6%, and -6.3% (Figure 1b). These negative difference may partly be caused by the relatively high number of measurements at high SZA in February. Large increase in TOMS data relative to Dobson for measurements at high SZA were found especially at Reykjavik (Figure 5) and Resolute. When averaged over 1° intervals of the SZA, the Dobson measurements at Reykjavik are up to 20% smaller than TOMS at SZA of 88° to 89°.

This is contrary to the results reported by Pommereau [1989], who found that the TOMS version 5 ozone content decreases relative to SAOZ (Système d'Analyse par Observation Zénithale) measurements at Dumont d'Urville and Greenland with increasing SZA. The SAOZ is constructed to measure at high SZA, so that these measurements should be more accurate and the error should lie in the TOMS data. Pommereau has found that the differences are largely reduced when using the TOMS version 6 data because of the additional standard profiles in the new algorithm for polar conditions (J.P. Pommereau, personal communication, 1991).

Since Dobson measurements are taken at SZA higher than 80° at the five stations, where they become unreliable [Komhyr, 1980], the results from Pommereau and from Figure 5 indicate that the Dobson measurements at SZA higher than 80° are particularly inaccurate.

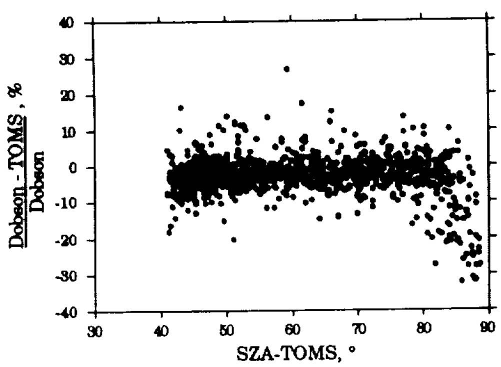


Fig. 5. Relative differences in total ozone at Reykjavik versus the solar zenith angle (SZA) at the time of TOMS measurements.

SUMMARY

The comparison between total ozone measurements from satellite (TOMS) and ground-based (Dobson) measurements show significant differences between the ground stations. For the years 1986 to 1989 the relative mean difference to TOMS can be calculated for each station. It is as high as +6.9% and +8.3% at Oslo and Longyearbyen but lower at the other stations and within the accuracy of ±3.6% for this comparison: Tromsø has a mean difference of +2.9%, and Resolute has a mean difference of +1.2%, while Reykjavik is the only station with a negative mean difference of -2.5%.

A drift of +1.2% per year in Oslo and +3.7% per year in Longyearbyen is found in the relative differences. Since there is no drift in the TOMS data from the algorithm version 6, the observed drift may be due to some drift in the Dobson instrument at the ground stations.

It can be shown from nearly simultaneous measurements in two different wavelength double pairs in Oslo that at least 2% of the difference results from the use of the CC' wavelengths instead of AD wavelengths. Since all Norwegian stations have used the CC' wavelengths exclusively, a similar error can be assumed for Tromsø and Longyearbyen. Since 1990 the Norwegian stations have also used the AD wavelength double pair if weather conditions permit (S.H.H. Larsen, personal communication, 1991) so this error should decrease in the measurements after 1989.

Another error source is mainly caused by the use of standard ozone profiles in the TOMS algorithm. The comparison between the tropospheric ozone amount in these standard profiles and from ECC ozonesonde measurements shows that the tropospheric ozone in the standard profiles used in the TOMS algorithm is too low, and this leads to an error of about 2% in total ozone.

Solar zenith angles in northern latitudes are higher than 80° during a significant part of the year. The relative differences between TOMS and Dobson total ozone show a higher scatter at large SZA, so that daily ozone values, in particular, may be in error.

REFERENCES

Basher, R.E., Review of the Dobson spectrophotometer and its accuracy, Rep. 13, Global Ozone Res. and Monit. Proj., World Meteorol. Organ., Geneva, 1982.

Bojkov, R.D., Ozone changes at the surface and in the free troposphere, in *Tropospheric Ozone*, edited by I.S.A. Isaksen, pp. 83-96, D.Reidel, Norwell, Mass., 1988.

Dave, J.V., and C.L. Mateer, A preliminary study on the possibility of estimating total atmospheric ozone from satellite measurements, *J.Atmos.Sci.*, 24, 414-427, 1967.

Fleig, A.J., D.S. Silberstein, C.G. Wellemeyer, R.P. Cebula, and P.K. Bhartia, An assessment of the long-term drift in TOMS total ozone data, based on the comparison with the Dobson network, *Geophys.Res.Lett.*, 15(10), 1133-1136, 1988a.

Fleig, A.J., A.J. Krueger, P.K. Bhartia, B.M. Schlesinger, R.P. Cebula, and C.G. Wellemeyer, Nimbus-7 total ozone mapping spectrometer (TOMS) data products users guide, *NASA Ref.Publ.* 1988b.

Herman, J.R., R. Hudson, R. McPeters, R. Stolarski, Z. Ahmad, X.Y. Gu, S. Taylor, and C. Wellemeyer, A new self-calibration method applied to TOMS and SBUV backscattered ultraviolet data to determine long-term global ozone change, *J.Geophys.Res.*, 96(D4), 7531-7545, 1991.

Komhyr, W.D., Operations handbook — Ozone observations with a Dobson spectrophotometer, Global Ozone Res. and Monit. Proj., Rep.6, World Meteorol. Organ., Geneva, 1980.

Komhyr, W.D., S.J. Oltmans, A.N. Chopra, and P.R. Franchois, Performance characteristics of high-altitude ECC ozonesondes. in *Atmospheric Ozone*, edited by C.S. Zerefos and A.Ghazi, pp. 499-501, D. Reidel, Norwell, Mass., 1985.

McPeters, R.D., and W.D. Komhyr, Long-term changes in the total ozone mapping spectrometer relative to the world primary standard Dobson spectrometer 83, *J.Geophys.Res.*, 96(D2), 2987-2993, 1991.

Pommereau, J.P., Ground-based stratospheric monitoring by ultraviolet and visible spectrometry, paper presented at *Die nordpolare Stratosphäre im Winter 88/89*, BMFT-Workshop,Federal Min. for Res. and Techn., Bonn, Germany, June, 12-13,1989.